GENerators for Small Electrical and Thermal Systems (GENSETS)

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PLEASE NOTE: A prior Letter of Intent is not required for this specific FOA from DOE-ARPA-E.

SUMMARY

The GENSETS Program – GENerators for Small Electrical and Thermal Systems – seeks to fund the development of potentially disruptive generator technologies that will enable widespread deployment of residential Combined Heat and Power (CHP) systems. Here, CHP is defined as the distributed generation of electricity from piped-in natural gas fuel at a residence or a commercial site complemented by use of exhaust heat for local heating and cooling. If adopted widely by U.S. residential and commercial sectors, GENSETS CHP systems could lead to annual primary energy savings of more than 5 quadrillion BTU (quads). GENSETS systems could also provide annual CO_2 emissions reductions of more than 200 million metric tons, which is roughly 10% of the CO_2 produced annually from U.S. electricity generation and 4% of total U.S. annual CO_2 emissions.

The GENSETS Program seeks transformative generators/engines with 1 kW of electrical output (kWe) that have high efficiency (40% fuel to electricity), long life (10 years), low cost ($3,000 per system), and low emissions. Heat engines and generators capable of achieving these targets may include internal and external combustion engines, turbines, and solid state devices such as thermophotovoltaics, thermionic emitters, and thermoelectrics. It is anticipated that the same technologies developed for 1-kWe engines in GENSETS could be adapted to build larger engines with

even higher efficiencies for various commercial sectors of the U.S.

PROGRAM OBJECTIVES

All the current state-of-the-art engines for CHP suffer from low efficiency and high cost. The ARPA-E GENSETS program is seeking fundamentally disruptive technologies that can markedly improve the fuel to electricity efficiency to 40% while delivering 1 kWe electrical power at low cost. The total system cost should not exceed $3,000 at high volume (e.g., 1 million unit scale) (excluding $1,400 installation and balance of plant costs). These technologies must meet the emissions requirements documented in detail in Section I.F of the FOA. The key program objectives are outlined below in detail:

Achieve 40% fuel-to-electrical power generation efficiency

- The goal of the ARPA-E GENSETS program is to leverage existing technologies and encourage disruptive concepts that can realize the 40% electrical efficiency target and deliver low cost 1 kWe systems for residential CHP applications.

Comply with emissions standards

- Widespread deployment of CHP systems would result in significant reduction in CO2 emissions as compared to central-station power plants. However, significant challenges exist in reducing CO, NOx and VOCs in natural gas powered CHP systems at the 1 kWe size. Through the GENSETS FOA, ARPA-E is expecting generator concepts with high combustion efficiencies that produce emissions that comply with both the 2007 CARB emissions regulations on NOx, CO and VOCs and the EPA NSPS limit on PM. A system-out GHG limit is set at 1100 CO2eq lb/MW-hr to ensure compliance with prevailing state-level environmental standards.

Achieve long lifetime/durability

- The target for the total system life is 10 years with a capacity factor of 99.9%, i.e., the system should have the capability of running continuously between services (e.g., oil change or cathode replacement) which should not be more than once a year, corresponding to about 8,000 running hours between service intervals. Based upon reported performance, this is a realistic goal to achieve for ICEs and Stirling engines. For example, for a 1 kWe CHP system, a manufacturer reports 6,000 running hours or 3 years between service, which is close to the target set by this FOA. Also, a Stirling engine manufacturer has demonstrated maintenance-free operation for 100,000 hours (11 years) and eight other engines have more than 8,000 hours and are still running. The system lifetime target will be a challenge for new device types that are still rapidly-evolving in design such as solid state devices and micro-turbines. Accelerated testing should be used by GENSETS performers to project actual field lifetimes from shorter duration test data.

Reduce system cost to enable widespread penetration of residential CHP

- The total CAPEX here includes the system cost but excludes the installation and balance of plant costs. The CAPEX target for the 1 kWe system is no more than $3,000.

TECHNICAL CATEGORIES OF INTEREST

The ARPA-E GENSETS program will fund transformational technologies that can create a paradigm shift in the residential heat and power generation process. ARPA-E expects GENSETS to open pathways for high-efficiency, low-emissions, long-life, cost-effective, 1-kWe generators that can enable significant energy savings and CO2 emissions reduction.

Applicants must present a well-justified, realistic proposal for the design, construction, and demonstration of a complete engine/generator system that meets all the technical performance targets. Specifically, the systems should accept natural gas at standard residential delivery pressures as their only fuel input and produce 60 Hz ac electrical output at 110 V.

Example technologies of interest, either as standalone solutions or in combinations, include, but are not limited to:

- Internal combustion engines

- External combustion engines such as Stirling engines and steam engines

- Any other novel engines (e.g. detonation engines, thermoacoustic engines, free-piston engines, rotary engines etc.)

- Combustion turbines such as micro-turbines

- Micro Rankine cycles

- Novel concepts that incorporate exhaust and coolant waste-heat recovery, reduced mechanical friction and reduced heat transfer

- Novel concepts to improve combustion efficiency and emissions reduction such as exhaust gas recirculation (EGR) or flue gas recirculation (FGR), homogeneous charge compression ignition (HCCI), spark-assisted HCCI (SA-HCCI), corona ignition, and laser ignition

- Thermophotovoltaics

- Thermionic emitters

- Thermoelectric generators

- Pyroelectrics

- Ion expansion electrochemical devices for electricity generation

- Innovative integration of topping cycles and/or bottoming cycles

- Combinations of the above devices and concepts

Supplementary Explanations of Targets

1.1 The system concept should target 1-kWe generation. However, if the efficiency target is demonstrated in a device which has < 1-kWe power producing capacity, then a detailed scaling analysis should be presented to project efficiency at 1-kWe. Systems larger than 1-kWe are not of interest.

1.2 Natural gas fuel to ac electricity conversion efficiency is based on lower heating value (LHV) of pipeline natural gas with 983 Btu per cubic foot. Individual component efficiencies of 40% are not sufficient. A device delivering 40% electrical efficiency relative to its input heat energy is not acceptable. Solid-state devices should be treated as external combustion engines and electrical efficiency should be described as in Eq. 1 ($\eta e = \eta comb \bullet \eta ind \bullet \eta m \bullet \eta alt$).

1.3 Residential hot-water and space heating output provided by CHP system should be > 1 kW/kWe at > 80 °C.

1.4 The system is expected to run continuously between the scheduled regular maintenance and restart easily.

1.5 The engine/generator system, including emissions mitigation and dissipation of exhaust heat (when not fully used), must plausibly cost less than $3,000 per kWe in large production volumes (e.g., one million units). The $3,000 cost of the generator system itself includes all components needed to take pipeline natural gas and produce electricity (ac, 60 Hz) and exhaust heat as outputs; the costs of installation (labor) and balance of plants (smart meters and heat exchangers for integration with other systems) of ~$1,400 are not included. An alternator efficiency (ηalt) of 0.8 to 0.96 can be assumed for the purpose of FOA application if the alternator is not integral to the generator under development. The alternator cost needs to be included in the system CAPEX. The cost of commercially available alternators varies essentially linearly as the efficiency increases from 0.8 to 0.96 according to: Alternator cost [$] = 3250*ηalt – 2520. Systems that do not need an alternator can exclude this cost.

1.7-1.9 Emissions for NOx, CO and VOCs should comply with CARB 2007 emissions limits for distributed power generation. Full applications must provide a complete discussion relative to the state-of-the-art numbers in a specific category of technology (e.g. ICE) and how improvements are made with respect to the baseline performance in the literature. Mitigation technologies are allowable as long as the cost is included in the system CAPEX.

1.10 For GHG emissions, only CO2 and CH4 are considered by the GENSETS Program. CO2eq value for CH4 must be evaluated using its 100 year GWP value of 28, i.e., 1 g of CH4 corresponds to 28 g of CO2eq. The total system-out CO2eq must be less than 1100 lb/MW-hr.

1.13 The system must be able to operate at methane numbers as low as 70. Methane number is defined using the following equations:

Motor octane number (MON) = -406.14 + 508.04*(H/C) – 173.55*(H/C) 2 + 20.17*(H/C) 3

Methane number (MN) = 1.624*MON – 119.1. H/C is the fuel hydrogen to carbon ratio.

A Wobbe index of 1328 ±8% is allowed to accommodate different natural gas compositions.

APPLICATIONS SPECIFICALLY NOT OF INTEREST

The following types of applications will be deemed nonresponsive and will not be reviewed or considered (see Section III.F.2 of the FOA):

- Applications submitted by entities or organizations other than Small Business Concerns.

- For the STTR program, applications submitted without one Research Institution as a member of the project team.

- Applications that fall outside the technical performance targets specified in Section I.F of the FOA

- Applications for basic research aimed at discovery and fundamental knowledge generation.

- Applications for large-scale demonstration projects of existing technologies.

- Applications for proposed technologies that represent incremental improvements to existing technologies.

- Applications for proposed technologies that are not based on sound scientific principles (e.g., violates a law of thermodynamics).

- Applications for proposed technologies that are not transformational, as described in Section I.A of

the FOA.

- Applications for proposed technologies that do not have the potential to become disruptive in nature, as described in Section I.A of the FOA. Technologies must be scalable such that they could be disruptive with sufficient technical progress.

- Applications that are not scientifically distinct from existing funded activities supported elsewhere, including within the Department of Energy.

- Applications that propose the following:

o CHP systems that employ fuel cells (ARPA-E has previously solicited for innovative fuel cell technology for distributed generation applications through its REBELS FOA)

o Internal and external combustion systems that are powered by fuels other than natural gas, e.g., gasoline and diesel engines.

o Employment of dual-fuel combustion such as diesel/natural gas fuel blends

o Concepts with more than 1-kWe power generation capacity

o Systems that only focus on converting heat to electricity and that do not consider natural gas to electricity conversion.

Questions about this FOA? Check the Frequently Asked Questions available at http://arpa-e.energy.gov/faq. For questions that have not already been answered, email ARPA-E-CO@hq.doe.gov (with FOA name and number in subject line); see FOA Sec. VII.A.

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